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Evaluation of the interim measurement protocol for railway noise source description

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Abstract

The Dutch national calculation scheme for railway noise has been declared the default interim method for railway noise calculation by the EU, until the introduction of results from the Harmonoise project. It includes a measurement protocol for determining emission input data in the format suitable for the present calculation scheme. The calculation scheme contains a fixed database of emission data for common Dutch rolling stock. The measurement protocol provides for the addition of emission data of new or foreign rolling stock. This is relevant for the Netherlands, as such rolling stock increasingly appears on the network, but also for other European countries that are going to use the interim method, since emission data for their rolling stock have to be established.

The protocol features two procedures. Procedure A allows using the existing fixed database of emission data. Selection of a particular dataset (or ‘category’) can be based on external appearance of rolling stock (without measurements) or pass-by sound pressure level measurements at a site with known rail roughness. If a user finds that none of the existing data sets properly represent its rolling stock, the optional procedure B is available. This procedure assesses pass-by levels, track and wheel roughness levels. The measurement protocol is based on a type-test-like procedure requiring controlled conditions for the vehicle and track.

A measurement campaign has been undertaken to test procedures A and B. This campaign coincided with a Swiss campaign to establish the sound emission of freight vehicles equipped with composite block brakes. The test of the protocol was focussed both on the practicability of the required measurements and on the unambiguity and comprehensiveness of the test. Open questions, findings, resulting conclusions and recommendations regarding the protocol are discussed here.

1. Introduction

The Dutch national calculation scheme for railway noise [1] has been declared the default interim method [2–5] for railway noise calculation by the EU, until the introduction of results from the Harmonoise project. It includes a measurement protocol for determining emission input data in the format suitable for the present calculation scheme. The calculation scheme contains a fixed database of emission data for common Dutch rolling stock. The measurement protocol provides for the addition of emission data of new or foreign rolling

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stock. This is relevant for the Netherlands, as such rolling stock increasingly appears on the network. Furthermore, it is relevant for other European countries that are going to use the interim method, since emission data for their rolling stock have to be established.

After a description of the interim method and the measurement protocol, results from a measurement campaign to evaluate the protocol are shown and discussed.

2. Outline of interim method for railway noise

The EU interim method for the prediction of railway noise [5] is based on the Dutch method RMR 96 [1]. The main features of the Dutch prediction model are the following:

- it is based on a limited number of feature-based train categories and works with vehicle units;
- it works in octave bands (SRM II, most relevant here) or in overall dB(A) levels (SRM I);
- it includes constant speed, braking and impact noise;
- five source heights are included;
- several track types and bridges are included;
- the existing emission data are obtained from multiple statistical measurements.

In 2000, a measurement protocol was proposed [6,7] to formalise a method to acquire emission data for new rolling stock. In the past, this was done only on a statistical basis, requiring large numbers of measurements. With the increased numbers of new rolling stock, it was considered most practical to base emission measurements on a single test similar to a type test. In the same period, measurement methods were developed in European projects (Metarail [8] and STAIRRS [9]) that provided a better basis for taking wheel/rail roughness and vibro-acoustic transfer into account. These were included as far as the existing calculation scheme allowed. It was foreseen that, future versions and in particular the Harmonoise model would require the proper use of such methods to benefit fully from the potential noise reduction due to vehicle and track-related measures.

The description here is limited to the emission part of the interim methods. The octave band prediction model works with emission terms for non-braking and braking vehicles. $E_{h,i,c}$ is the emission term (sound power per kilometre train length) for non-braking vehicles in octave band i ($i = 1, 2, \ldots, 8$ with centre frequencies 63, 125, 250, 500, 1000, 2000, 4000, 8000 Hz) and at source height h, $E_{\mathrm{br},h,i,c}$ is the same, but for braking vehicles; c is the number of the vehicle category. These emission terms are given in the form,

$$E_{h,i} = a_{h,i,c} + b_{h,i,c} \lg v + 10 \lg Q_c + c_{bb,i,m,c}, \tag{1}$$

where $a_{h,i,c}$, $b_{h,i,c}$ are factors (dB) tabulated for each source height h and vehicle category c in octave bands, v is the train speed (km/h), Q_c is the number of vehicle units per hour, lg is $\log_{10}$ and $c_{bb,i,m,c}$ is a correction term for track type bb and condition m. At a single point near the track, the equivalent sound pressure level for a single train type and speed, on default track and with no barriers or reflections, can be calculated from

$$L_{\mathrm{eq},ih} = E_{h,i} + \Delta L_{GU} - \Delta L_{OD} - 58.6, \tag{2}$$

where ΔL_{GU} is the attenuation due to distance (dB) and ΔL_{OD} is attenuation due to ground and air absorption (dB) (see Refs. [1,7] for definitions). The constant value of 58.6 accounts for various corrections such as reference values and the conversion of sound power to sound pressure containing distance and surface quantities. Methods for determining emission terms should provide the terms $a_{h,i,c}$, $b_{h,i,c}$ for a given new vehicle category or indicate which category a new vehicle can be assigned to.

3. Methods for emission measurement

3.1. Two procedures

Two procedures are defined to obtain emission data for new rolling stock. Procedure A allows the existing fixed database of emission data to be used. Selection of a particular dataset (or 'category') can be based on external appearance of rolling stock, braking system and powertrain type (without measurements) or on pass-by sound pressure level measurements on a site with known rail roughness. Procedure B is intended for situations where existing vehicle categories are not suitable, and provides a more detailed description of the vehicle, taking wheel and rail roughness and track/vehicle contributions into account. Procedure B is consistent, although not identical to the future Harmonoise methods.

The measurement protocol is based on a type-test-like procedure requiring controlled conditions for the vehicle and track, both for procedure A and B. The track should have concrete sleepers (monoblock or biblock) and stiff railpads (static stiffness > 500 kN/mm at 60 kN preload). Measuring speeds are in ranges 10–30, 30–60, 60–90, 90–120, 120–160, 160–220 km/h and 220 km/h$-v_{\max}$.

3.2. Procedure A

In Procedure A, the measured noise level in octave bands is compared with the level predicted by the calculation method, taking the rail roughness at the test site into account. If the measured level corrected for rail roughness is below the predicted spectrum of the selected train category, the vehicle in question may be put into that category. It is essential that such a vehicle is representative of a whole batch on which future calculations will be based. The acceptance condition is

$$L_{p\mathrm{eq}}, T_{p,i,\mathrm{meas}}(v) + L_{\mathrm{diff},i} < L_{p\mathrm{eq},Tp,i,m,\mathrm{pred}}(v), \tag{3}$$

where $L_{p\mathrm{eq},T_p}$ is the equivalent sound pressure level of a vehicle pass-by at 7.5 m (dB re 2×10^{-5} Pa), T_p is the transit time (= train length/speed) (s), i is the octave band number, v is speed, meas indicates measured and pred indicates predicted. $L_{\mathrm{diff},i}$ is a constant or spectrum defined as follows:

- $L_{\mathrm{diff},i} = 1$ for speeds at which traction or aerodynamic noise dominate;
- $L_{\mathrm{diff},i} = 1$ for speeds at which rolling noise dominates and wheels are cast-iron block-braked;
- $L_{\mathrm{diff},i} = 1 + Y_i$ for speeds at which rolling noise dominates and wheels are not cast iron block-braked, i.e. disc, composite block, drum-braked or otherwise, where Y_i is defined as

  $$Y_i(v) = L_{r\mathrm{tr},i}(v) \oplus L_{r\mathrm{veh},c}(v) - L_{r\mathrm{tr},NL,i}(v) \oplus L_{r\mathrm{veh},c}(v), \tag{4}$$

  where $\oplus$ indicates energy summation, $L_{r,i}(v)$ (dB re 1 μm) denotes roughness in octave frequency band i at train speed v, tr denotes track, veh denotes vehicle, NL is average Dutch network and c denotes vehicle category. The average network rail roughness $L_{r\mathrm{tr},NL,i}(v)$ and default wheel roughness for known categories are tabulated in Ref. [7] and originate from the work from Ref. [10], but the wheel roughness may also be measured if data is available. $L_{\mathrm{diff},i}$ is reduced by 1 if the vehicles to be tested are at least 5 in number and if they are in regular service. If the acceptance criterion is exceeded in some octave bands this is allowed as long as the average excess over all speeds and bands does not exceed 1.5 dB.

3.3. Procedure B

Procedure B provides a means to determine noise emission data of a new vehicle more accurately taking the wheel/rail roughness and vibro-acoustic transfer function of track and vehicle into account. Traction, rolling and aerodynamic noise are characterised separately. First expressions are derived for each of these sources as equivalent sound pressure levels, then emission quantities are given.

3.3.1. Rolling noise

Rolling noise emission data is determined in terms of effective roughness and transfer functions from roughness to sound pressure, adjusting the data to the average rail roughness for the Dutch network.

The effective roughness $L_{r\mathrm{tr}}(\lambda)$ (dB re 1 μm) is direct roughness (as in prEN ISO 3095:2001 [11]) $L_{r\mathrm{tr,dir}}(\lambda)$ corrected for the contact filter $A_3(\lambda)$:

$$L_{r\mathrm{tr}}(\lambda) = L_{r\mathrm{tr,dir}}(\lambda) + A_3(\lambda), \tag{5}$$

where λ denotes roughness wavelength (m), which can also be replaced by frequency and speed. The contact filter is tabulated in Ref. [7] or can be calculated theoretically; it depends on wheel diameter and wheel load (see Ref. [12]). In the following, all roughness is effective roughness unless indicated as unfiltered roughness by subscript dir.

The equivalent pass-by sound pressure level $L_{peq}(f)$ at 7.5 m distance from the track centreline can be written as

$$L_{peq,\mathrm{tot}}(f) = L_{r\mathrm{tot}}(f, v) + L_{Hpr,nl,\mathrm{tot}}(f) + 10\lg\frac{N_{\mathrm{ax}}}{l_{\mathrm{veh}}}, \tag{6}$$

where $L_{r\mathrm{tot}}(f, v)$ is the frequency spectrum of combined effective roughness of wheel and rail at speed v, N_{ax} is the number of axles and l_{veh} the vehicle length (m), $L_{Hpr,nl,\mathrm{tot}}(f)$ is a transfer function from effective roughness to sound pressure, normalised to the axle density $N_{\mathrm{ax}}/l_{\mathrm{veh}}$ (dB re 20 Pa/$\sqrt{}$m). This transfer function can be measured from a pass-by (time = T_p), where the combined effective roughness can be determined from Eq. (7), or using the techniques described in Ref. [12]. The total effective roughness $L_{r\mathrm{tot}}(f)$ is determined from vertical railhead vibration during a pass-by at speed v:

$$L_{r\mathrm{tot}}(f, v) = L_{v\mathrm{eq}}(f, v) + 10\lg\left(\frac{D_s(f)}{8.68N_{\mathrm{ax}}/l_{\mathrm{veh}}}\right) - A_2(f) - 20\lg(2\pi f), \tag{7}$$

where $L_{v\mathrm{eq}}(f, v)$ is the equivalent vertical railhead vibration level during a pass-by (dB re 10^{-6} m/s), $D_s(f)$ is the vertical track decay rate in one-third octave bands (dB/m) and $A_2(f)$ is the difference spectrum between the rail displacement in the contact point and the effective roughness. $A_2(f)$ is tabulated in Ref. [7] and can also be calculated theoretically [12]. Spatial decay $D_s(f)$ can be determined from pass-by measurement [12] or from hammer impact response measurements [13].

The combined effective roughness $L_{r\mathrm{tot}}$ is the energy sum of effective wheel roughness $L_{r\mathrm{veh}}$, and rail roughness $L_{r\mathrm{tr}}$:

$$L_{r\mathrm{tot}} = L_{r\mathrm{veh}} \oplus L_{r\mathrm{tr}}, \tag{8}$$

where $\oplus$ indicates energy summation. The effective wheel roughness is estimated from,

$$L_{r\mathrm{veh}}(f) = 10\lg(10^{L_{r\mathrm{tot}}(f)/10} - 10^{L_{r\mathrm{tr}}(f)/10})$$

$$\text{and if } L_{r\mathrm{tot}}(f) - L_{r\mathrm{tr}}(f) < 1 : L_{r\mathrm{veh}} = L_{r\mathrm{tot}}(f) - 7 \text{ and } L_{r\mathrm{tr}}(f) = L_{r\mathrm{tot}}(f) - 1 \tag{9}$$

or if available, direct roughness measurement (but then filtered for the contact patch) could be used. The track roughness $L_{r\mathrm{tr}}$ is known from direct measurement and is converted to effective roughness with Eq. (5).

As the prediction scheme requires emission data for average track conditions, an average rail roughness for the (Dutch) network is introduced $L_{r\mathrm{tr,net}}$, tabulated in Ref. [7] and shown in Fig. 1 which is used to determine an average combined effective roughness for the network $L_{r\mathrm{tot,net}}$:

$$L_{r\mathrm{tot},NL} = L_{r\mathrm{veh}} \oplus L_{r\mathrm{tr,net}}. \tag{10}$$

The partial contributions from track $L_{p\mathrm{tr}}$ and vehicle $L_{p\mathrm{veh}}$ are required for the source heights at 0 m (track) and 0.5 m (axle). These can be obtained in various ways: by using a quiet reference vehicle, by tabulation (see for example Ref. [14]) or by other methods, such as those developed in STAIRRS [9]. In any case, the partial contributions produce the total level when energy added.

The reference vehicle method requires an extra pass-by with wagons with low sound radiation in comparison with the track. This can be achieved with massive wheels with diameters below 700 mm and a vehicle with little or no superstructure, or well-isolated superstructure. Examples of such vehicles are given in Ref. [14]. A special transfer function $L_{Hpv,\mathrm{tr}}(f)$ is measured during pass-by of the reference vehicles, between vertical railhead vibration and sound pressure. This function is not sensitive to the contact patch. It is used to derive the track contribution $L_{p\mathrm{tr}}(f, v)$ of the normal test vehicle at speed v:

$$L_{p\mathrm{tr}}(f, v) = L_{Hpv,\mathrm{tr}}(f) + L_v(f), \tag{11}$$

where $L_{Hpv,\mathrm{tr}}(f)$ is the transfer function measured with the reference vehicle (dB re 20 Pa/m/s) and $L_v(f)$ is the equivalent railhead vertical vibration level during pass-by. The vehicle sound contribution can be estimated in

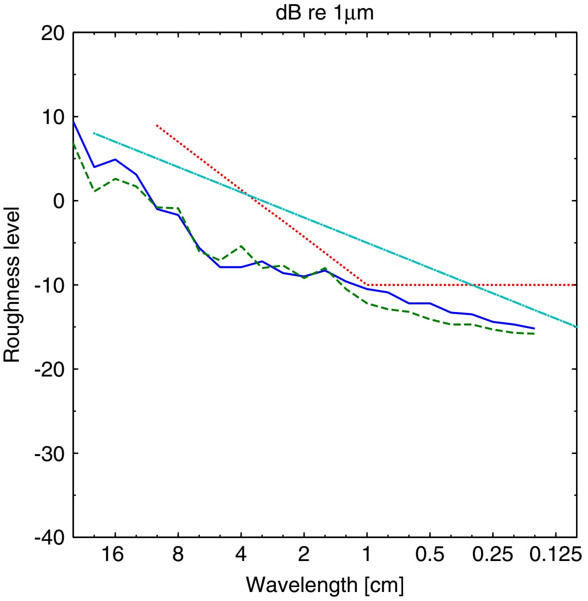

Fig. 1. Directly measured rail roughness levels in one-third octave bands for the left and right rail of the test site, —, left rail; – – –, right rail; together with the prEN ISO 3095:2001 limit (· · · · · ·) and the average rail roughness for the Dutch network (– · – ·).

analogy to the vehicle roughness in Eq. (9):

$$L_{p\text{veh}}(f) = 10\,\lg(10^{L_{p\text{tot}}(f)/10} - 10^{L_{p\text{tr}}(f)/10})$$

$$\text{and if } L_{p\text{tot}}(f) - L_{p\text{tr}}(f) < 1 : L_{p\text{veh}} = L_{p\text{tot}}(f) - 7 \text{ and } L_{p\text{tr}}(f) = L_{p\text{tot}}(f) - 1. \tag{12}$$

These track and vehicle contributions must now still be converted to the average roughness situation. This is done by splitting Eq. (6) and inserting the corrected effective roughness for average track:

$$\begin{aligned} L_{Hpr,nl,\text{tr}}(f) &= L_{p\text{eq,tr}}(f) - L_{r\text{tot}}(f,v) - 10\,\lg\frac{N_{\text{ax}}}{l_{\text{veh}}}, \\ L_{Hpr,nl,\text{veh}}(f) &= L_{p\text{eq,veh}}(f) - L_{r\text{tot}}(f,v) - 10\,\lg\frac{N_{\text{ax}}}{l_{\text{veh}}}, \end{aligned} \tag{13}$$

$$\begin{aligned} L_{p\text{eq,tr}}(f) &= L_{r\text{tot,net}}(f,v) + L_{Hpr,nl,\text{tr}}(f) + 10\,\lg\frac{N_{\text{ax}}}{l_{\text{veh}}}, \\ L_{p\text{eq,veh}}(f) &= L_{r\text{tot,net}}(f,v) + L_{Hpr,nl,\text{veh}}(f) + 10\,\lg\frac{N_{\text{ax}}}{l_{\text{veh}}}. \end{aligned} \tag{14}$$

The spectra from Eq. (14) are then converted from one-third octave to octave spectra resulting in $L_{p\text{eq,veh2},i}$ and $L_{p\text{eq,tr},i}$ where i denotes the octave band. Vehicle noise is set at source height 0.5 m and track noise at height 0 m.

3.3.2. Traction noise

Traction noise is determined for locomotives from acceleration tests at maximum acceleration for 0–60, 20–60 and 40–60 km/h. The equivalent sound pressure level in octave bands during the transit time T_p is measured at 7.5 m from the track centreline, 1.2 m above the rail surface, and at positions at 5 and 20 m ahead of the starting point. For each pass-by the equivalent sound pressure level and the speed is registered at the microphone position; a linear relation is determined between sound pressure level and speed for all octave bands resulting in

$$L_{p\mathrm{veh}1,i}(v) = x_i + y_i \lg v, \tag{15}$$

where $L_{p\mathrm{veh}1,i}(v)$ is the sound pressure level due to traction noise in octave bands, x_i and y_i are coefficients.

For other vehicles such as powered train units a only constant speed test is done at 20, 40 and 60 km/h at a single position at 7.5 m from the track. The same relation is derived as given in Eq. (15). The traction noise is assigned to different source heights if appropriate. This is done either by known physical location or by special measurement methods as described in Ref. [7]. If a source is distributed over several heights, the energy sum of partial sources at different height should equal the total traction noise level. Traction noise sources will be found at the height of the axle, floor, side walls and roof (e.g. exhaust).

3.3.3. Aerodynamic noise

If it can be shown that aerodynamic noise is relevant for prediction purposes, it can be measured at 250 km/h and steps of 50 upwards until maximum speed. It is measured at 25 m and converted back to 7.5 m. Several pass-bys are used to obtain a linear relation of the form

$$L_{p\mathrm{veh}3,i}(v) = x_i + y_i \lg v. \tag{16}$$

where $L_{p\mathrm{veh}31,i}(v)$ is the sound pressure level at 7.5 m due to aerodynamic noise in octave bands, x_i and y_i are coefficients. Source heights can be at 0.5 m (bogies), 2 m (wagon connections), 4 m (roof and recesses) and 5 m (pantograph). Determining source heights is best done with antenna measurements.

3.3.4. Braking noise

Braking noise is only taken into account if it exceeds the other sources by more than 1 dB. It is measured at 7.5 m distance while braking from approximately 25, 50, 75, 100 km/h and maximum speed. The speed and transit equivalent level $L_{p\mathrm{eq},T_p}$ are registered and a linear approximation in octave bands is derived:

$$L_{p\mathrm{br},i}(v) = x_i + y_i \lg v, \tag{17}$$

where $L_{p\mathrm{br},i}(v)$ is the braking noise level in octave bands as a function of speed v.

3.4. Emission terms

The emission terms $E_{h,i,x}$ for a new category x are now determined from Eqs. (14), (15) and (16) and where relevant also with source heights j, so from $L_{p\mathrm{veh}1,hi}$, $L_{p\mathrm{veh}2,hi}$ and $L_{p\mathrm{veh}3,hi}$:

$$E_{h,i,x} = L_{p\mathrm{veh}1,hi} \oplus L_{p\mathrm{veh}2,hi} \oplus L_{p\mathrm{veh}3,hi} \oplus L_{p\mathrm{tr},hi} + L_{m,i}, \tag{18}$$

where $E_{h,i,x}$ is the emission term for category x (dB(A)), source height h in octave band i. $L_{p\mathrm{tr},hi}$ is omitted for source heights above 0 m. $L_{m,i}$ is a conversion term (dB) between sound pressure and the emission term given as

$$L_{m,i} = 10 \lg \frac{Tp}{3600} - 10 \lg n - 10 \lg \left(\frac{1}{25} \sum_{k=-12}^{k=12} 10^{(D_{L,i}+D_{B,i}-\Delta L_{GU}(\Phi_k))/10} \right) + L_{FA,i} + 58.6, \tag{19}$$

where T_p is transit time, n is the number of wagons, Φ_k is the view angle given by $k \times 5^\circ$ (total view angle $= 25 \times 5^\circ = 125^\circ$), D_L is attenuation due to absorption in air (dB), D_B is ground attenuation (dB), ΔL_{GU} is attenuation due to distance (all as described in Ref. [7]) and $L_{FA,i}$ is the octave band filter (dB).

For braking noise the same emission terms are used with exception of the one at axle height (0.5 m) which is taken as

$$E_{h,\mathrm{br},i,x} = \max\{E_{h,i,x}, L_{p\mathrm{br},i} + L_{m,i}\}. \tag{20}$$

A final step is taken to determine emission factors $a_{h,i,x}$ and $b_{h,i,x}$ in Eq. (1). The emission term $E_{h,i,x}$ (dB) is now known at any speed v, and $a_{h,i,x}$ and $b_{h,i,x}$ can be obtained from a fitting procedure for Eq. (1). The same is done for the braking emission terms $E_{\mathrm{br},h,i,x}$ (dB).

4. Evaluation

A measurement campaign has been undertaken to evaluate procedures A and B [14,15]. This campaign was combined with a Swiss campaign to establish the sound emission of freight vehicles equipped with composite block brakes. A long test train with groups of different freight wagons was used. The track had smooth UIC 60 rails, concrete sleepers and stiff railpads, compliant with the European High Speed TSI 2002.

For procedure A, the actual protocol was found to be practical although the original acceptance criterion (see Ref. [15]) for putting vehicles into an existing category was found to be too stringent and it was subsequently somewhat relaxed resulting in the description given in Section 3.2.

Procedure B was tested in relation to rolling noise and it was also found to be practical. Only sound pressure and railhead vibration is measured besides rail roughness. Some examples of intermediate results and findings are given in the following.

The rail roughness levels are shown in Fig. 1 for the left and right rail of the test site, together with the prEN ISO 3095:2001 limit and the average rail roughness for the Dutch network. Effective combined roughness is shown in Fig. 2 for cast-iron block-braked wagons and in Fig. 3 for composite block-braked wagons. A substantial difference can be seen as expected, due to the fact that rail roughness is well below the wheel roughness in both cases. A wide wavelength range is available when measurements are taken at several speeds.

The vibration transfer function $L_{Hpv}(f)$ is shown for several different vehicles with different wheel diameters in Fig. 4. The vehicle with the smallest wheels shows the lowest response between 200 and 5000 Hz and proved to be the most suitable as a reference vehicle. The Megafret wagon had wheels with 780 mm while the NiNa EMU had small running wheels on the articulation bogies with a diameter of 630 mm. An even better estimate for the track transfer function $L_{Hpv,\mathrm{tr}}(f)$ can be obtained by taking the minimum spectrum for all spectra in Fig. 4. Using the NiNa data, the partial contributions of the other wagons could be determined as shown in Fig. 5.

Transfer functions are shown in Figs. 6 and 7, for effective roughness to sound pressure, normalised to axle density $N_{\mathrm{ax}}/l_{\mathrm{veh}}$, as defined in Eq. (6) for SGNSS wagons. These functions are very stable. In Fig. 6, a track

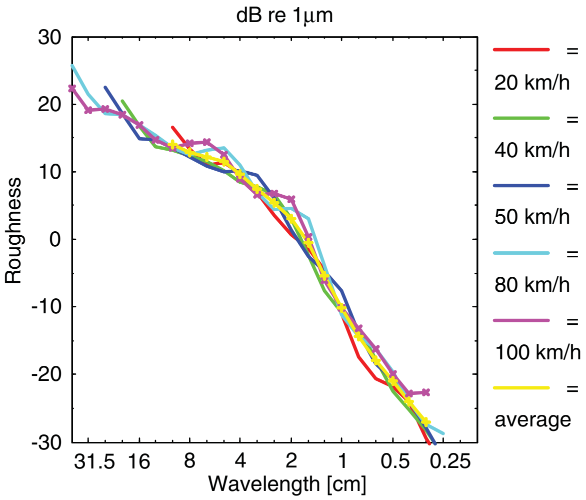

Fig. 2. Effective combined roughness in one-third octave bands of a cast iron block-braked SGNSS flat container wagon at several speeds, and the average, determined from rail vibration during pass-by with Eq. (7). —, 20 km/h; — — —, 40 km/h; · · · · · ·, 50 km/h; — · —, 80 km/h; ×—×, 100 km/h.

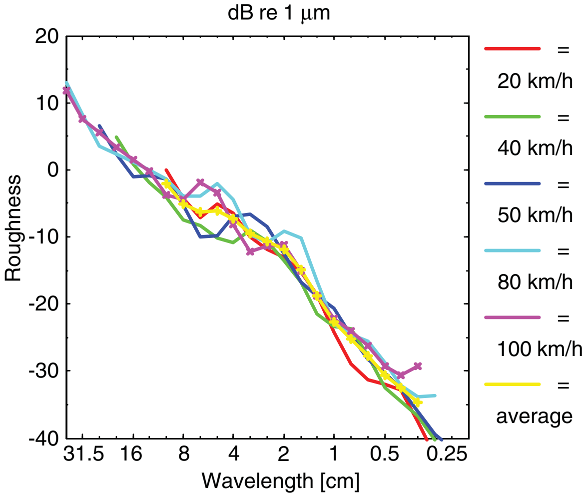

Fig. 3. Effective combined roughness in one-third octave bands of a composite block-braked SGNSS flat container wagon at several speeds, and the average, determined from rail vibration during pass-by with Eq. (7). —, 20 km/h; – – –, 40 km/h; · · · · · ·, 50 km/h; – · –, 80 km/h; ×—×, 100 km/h.

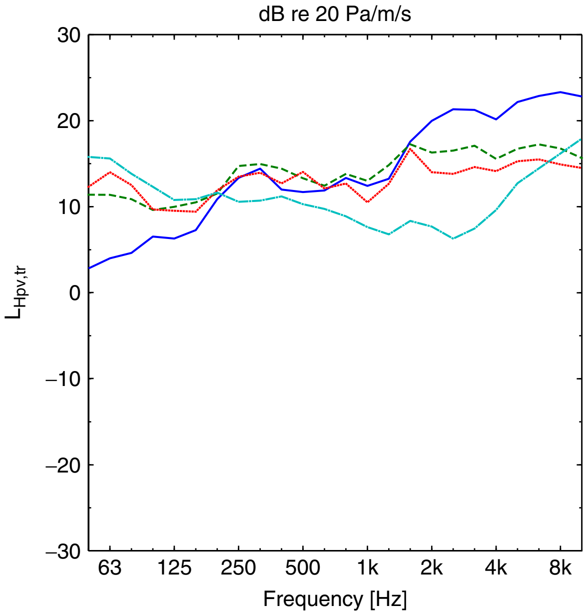

Fig. 4. Transfer function in third octaves of rail vibration to sound pressure $L_{Hpv}(f)$ for several vehicles; SGNSS has 920 mm diameter wheels, Megafret wagon has 780 mm diameter wheels, NiNa is an EMU (BLS) from which the middle Jacobs bogies with 630 mm diameter wheels have been used. —, SGNSS-GG; – – –, SGNSS-K; · · · · · ·, Megafret; – · – ·, NiNa.

transfer function is shown measured at different speeds, determined with the NiNa reference vehicle. Averaged transfer functions for vehicle and track are shown in Fig. 7. The vehicle contribution is somewhat overestimated below 800 Hz, but this is consistent with the method used and has no consequences for the model predictions.

Emission factors $a_{h,i,x}$ and $b_{h,i,x}$ are given for cast-iron block-braked wagons (SGNSS-GG) and composite block-braked wagons (SGNSS-K) in Table 1. These have been determined according to procedure B.

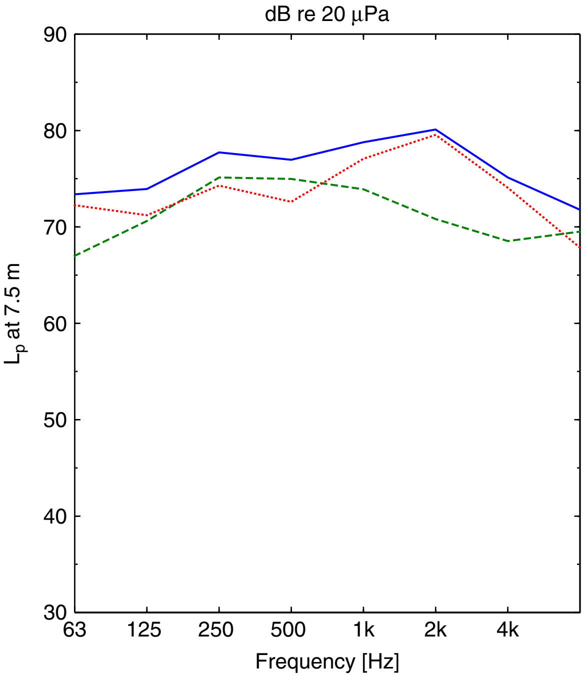

Fig. 5. Total and partial sound pressure levels in octave bands of a SGNSS wagon with composite brake blocks at 100 km/h determined with the reference vehicle method using the NiNa vehicle. —, total, 84.7 dB(A); – – –, track, 78.8 dB(A); · · · · · ·, vehicle, 83.4 dB(A).

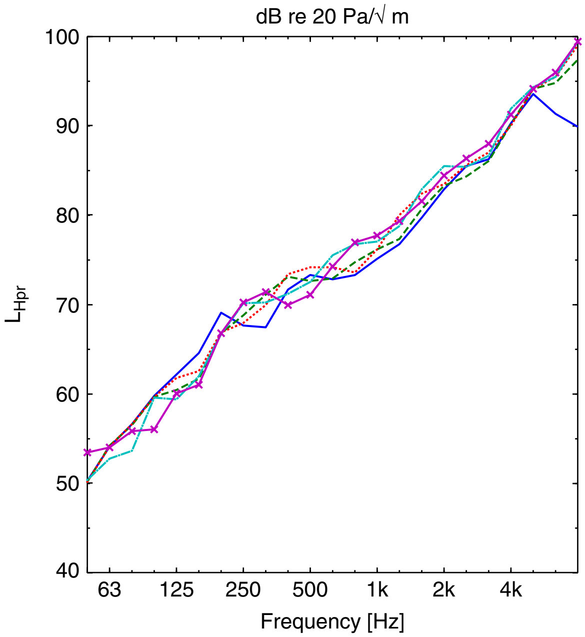

Fig. 6. Track transfer function in one-third octave bands determined for several speeds; based on NiNa as reference vehicle. Transfer function definition as in Eq. (6). —, 20 km/h; – – –, 40 km/h; · · · · · ·, 50 km/h; – · – ·, 80 km/h; ×—×, 100 km/h.

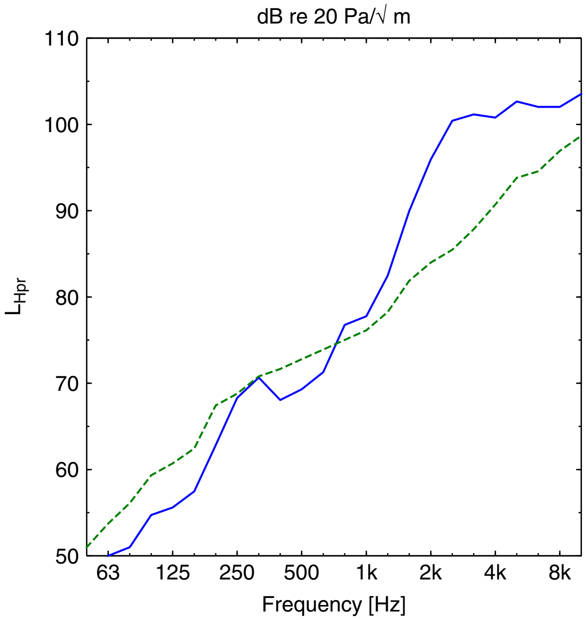

Fig. 7. Average track transfer function in one-third octave bands with average vehicle transfer function for SGNSS-GG wagons as derived with procedure B. Transfer function definition as in Eq. (6). —, vehicle, – – –, track.

5. Application issues

For the measurement of effective combined roughness it was found that most stable results are obtained by averaging in the wavelength domain.

For the reference vehicle it can be stated that it will produce acceptable results as long as it has a lower vehicle contribution than most other vehicles on the network in question. As long as the wheels are small and solid, and the wagon superstructure is not contributing, it will be suitable to estimate the vehicle and track contributions of other vehicles. For a given test site, the reference vehicle test does not need to be performed often, as the track transfer function will probably not change much over time. Examples of existing reference vehicle types are the NiNa (EMU), Laeks547, RoLa and Habikks. An alternative to the use of a reference vehicle is a distribution table as described in Ref. [14], or other special methods which include calculation [9]. If the vehicle to be measured is already a reference vehicle, a vehicle contribution is not needed and the emission terms are only used at 0 m source height.

If for a particular network the track is different from the test required, a different track can be used with the result that all emission data will differ, but will be applicable on that network. On some networks there may even be a strict limitation to a number of vehicle types. In that case, transfer functions can be determined for the whole vehicle–track combination, which then must be split into vehicle and track contributions by the most appropriate techniques available.

6. Conclusions

Two measurement procedures for determining emission terms for the interim railway noise calculation method have been presented and evaluated in a measurement campaign. Both protocols have proven to be robust for the considered track/vehicle combination. Some improvements have been proposed including the adjustment of the acceptance criterion for procedure A, and for the processing of effective roughness and transfer functions in procedure B. Examples of intermediate data have been provided.

Table 1
Emission factors for SGNSS-K and SGNSS-GG wagons for two speed intervals determined with procedure B

Category	Factor	Centre frequency for octave band i (Hz)							
		63	125	250	500	1K	2K	4K	8K
		1	2	3	4	5	6	7	8
$h = 0\,\mathrm{m}$									
K	a								
	$v<60$	43.9	61.8	59.7	41.7	47.2	62.3	68.1	68.3
	$v>60$	43.0	63.1	78.5	65.2	41.7	43.0	63.4	67.3
	b								
	$v<60$	−0.5	1.1	10.2	22.9	16.8	8.0	5.5	5.1
	$v>60$	0.1	0.3	−0.9	8.9	20.5	19.3	8.2	5.7
GG	a								
	$v<60$	49.6	72.8	71.6	51.9	36.6	46.5	58.7	68.1
	$v>60$	72.7	65.6	93.2	72.2	60.8	25.9	43.7	49.2
	b								
	$v<60$	2.1	0.1	9.6	23.0	30.2	21.7	12.6	5.3
	$v>60$	−11.4	4.2	−3.1	10.7	16.4	33.7	21.7	16.4
$h = 0.5\,\mathrm{m}$ (axle)									
K	a								
	$v<60$	49.9	62.5	58.1	41.3	54.6	71.4	72.8	65.7
	$v>60$	49.6	63.7	78.2	64.8	41.5	52.7	66.9	64.5
	b								
	$v<60$	−0.2	1.1	11.4	22.6	15.0	7.8	5.7	5.1
	$v>60$	0.0	0.2	−0.6	8.6	23.0	18.8	9.2	5.8
GG	a								
	$v<60$	45.2	68.1	70.5	45.9	40.4	57.8	67.0	73.4
	$v>60$	68.2	61.0	91.5	68.5	57.2	44.7	55.8	52.3
	b								
	$v<60$	2.0	0.0	9.4	24.3	29.1	22.1	14.4	5.4
	$v>60$	−11.4	4.1	−2.9	10.5	19.6	29.7	21.2	17.8

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